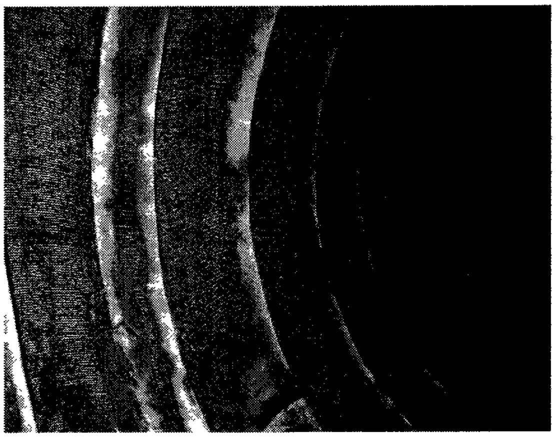
Customer
Objective: Minimize Impact of the Aging Plant
Initiative: Complete Unit 2 Circ Water Line Repairs.

History: The circulating water lines are critical to the operation of the generation stations. It is this critical dependance that necessitated the inspection of these lines after the failure of two sections of pipe. The inspections preformed in 2003 on unit 1 and unit 2 showed that many pipe sections of the circulating water line had broken wires from corrosion. It was decided that the best way to permanently repair these lines would be to use carbon fiber. The carbon fiber would restore structural integrity with out compromising the efficiency of the system.

Status: During the April 2008 outage the Gateway Company in conjunction with KPFF Consulting Engineering and IPSC Engineering installed carbon fiber in the unit 2 circulating water lines. The carbon fiber was installed using a patented three step process. This process consists of the preparation of the pipe, installation of the carbon fiber and application of the top protective coating.

Gateway Installing Carbon Fiber



Carbon Fiber Installed in Pipe

A total of 172 distressed sections of pipe have been repaired with carbon fiber over the past four years. Unit 1 repairs consisted of 38 sections repaired in 2005 and 32 sections repaired in 2007. Unit 2 which had the majority of the repairs had 56 section repaired in 2006 and 46 sections repaired in 2008.

About 90% of the carbon fiber repairs have been made to the return circulating water lines of unit 1 & 2 where the additional heat from the water has accelerated the corrosion process.

Future: Currently it is planned to install carbon fiber in 7 distressed section of pipe in unit 1 circulating water lines during the 2009 outage.

The inspection performed on unit 2 circulating water lines at the end of the 2008 outage has shown that out of the 48 previously distressed pipes that were not repaired, thirty seven have been found to have an increased number of wire breaks. The maximum increase in the total number of wire breaks in an individual pipe section is 145. The remaining 11 previously distress pipes remain unchanged.

The 2008 inspection also identified 11 newly distressed pipes since the 2003 inspection. A full analysis to determine how many of the remaining 59 distressed pipes will need to be repaired in 2010 has not been completed yet.

(925) 363-5917
Fax: (925) 363-5917
http://www.kta.com

KTA-TATOR, INC.
3523 Halfmoon Lane, Concord, CA 94518

INTRODUCTION

On April 10, 2008 Intermountain Power contracted with KTA-Tator, Inc. (KTA) to determine the cause of delaminations and blistering that was occurring on a carbon fiber reinforced lining that had been installed on large diameter cooling piping in Unit 2 at the Delta, UT power plant. The KPFF lining had been applied to numerous areas within the piping system over the last three years. During the 2008 spring Unit 2 outage large areas of the coating were found to be blistered and delaminated. Mr. Ray Tombaugh, Senior Consultant, was responsible for performing the investigation and preparing this report.

SUMMARY

There is widespread coating delamination and poor coating adhesion found throughout the piping in the Unit 2 cooling water system at the Intermountain Power Station in Delta UT. In this Unit, failure is primarily occurring between the KPFF ARC topcoats and the underlying Cabosil filled epoxy coating. To a lesser extent there are failures between layers of Cabosil filled material. These failures are primarily restricted to the fabric seam areas where an overcoat of Cabosil filled material is applied to the saturated fabric.

The cause of the failure is the formation of amine deposits (amine blush) on and in the Cabosil filled material and the ARC coating. Typically cool, damp conditions are required to cause amine blush – conditions that differ from the temperatures and humidity readings that were reported during the 2006 application. However, testing has shown that both materials will blush at laboratory conditions of 70 F and 50% humidity. Laboratory testing has also shown that the materials applied in the field were mixed at ratios consistent with the KPFF instructions. There is an inherent problem with the coating formulations since even undercatalyzed mixes (amine deficient) will blush at ideal application conditions.

Based on the field and laboratory investigation it is likely that additional failures will occur. The failures are likely to occur (1) within the same plane of failure (between ARC and Cabosil filled material) but (2) may also extend to other planes of failure, such as between layers of saturated fabric or between the primer and fabric layers. Additional destructive testing would be required in order to ascertain the extent of future failure. The testing would include comprehensive field adhesion testing and the removal of core samples of the material for laboratory investigation.

BACKGROUND

The following information was provided by Dahl Dalton and Jerry Hintze of Intermountain Power. The power plant was constructed in 1985 with several thousand feet of buried, concrete-lined, pre-stressed, steel cooling water piping. The piping ranges in size from 7' to 10' in diameter. The majority of the piping is 10' in diameter.

Some years after the plant became operational, breaches in the piping occurred. The piping was excavated at several areas and inspections determined that the strengthening rods had corroded. An engineering evaluation determined that the necessary loss in strength (from the corroded rods) could be regained by the application of a reinforced carbon fiber system to the interior of the pipe. A KPFF system was selected based upon its successful performance at the Palo Verdes nuclear plant.

The initial applications of the KPFF system were installed on Unit 1 in 2005. Additional applications were performed in 2007. Lining work began on Unit 2 and 2006 and then was reinitiated during the current 2008 outage. There are no product data sheets published for the material. Instruction sheets have been given to Intermountain Power.

The concrete surface is abrasive blasted to impart a profile. Any cracks that are present are repaired.

The coating system consists of the following layers:

1. A two component epoxy primer PRI 2002-3-R-A / PRI 2000-5-HR-B (Layer 1) is spray-applied directly to the concrete.
2. The same epoxy is mixed with Cabosil (Epoxy Protective Coating) and then trowel applied over the primer (Layer 2).
3. Into Layer 2 is placed the carbon fiber fabric that has been saturated on both sides with the Cabosil filled epoxy (Layer 3).
4. Over the fabric is applied another layer of Cabosil filled epoxy (Layer 4).
5. A second layer of saturated fabric is applied (Layer 5).
6. In Unit 1, a Cabosil filled layer (layer 6) was applied over the second fabric layer. However, after failures were observed in that unit, it was decided to eliminate that second Cabosil layer.
7. Currently, only the edges of the fabric are tapered smooth with additional Cabosil filled

epoxy (Layer 7) and one coat of primer (PRI 2002-3-R-A / PRI 2000-5-HR-B) was applied to the entire surface.

8. Over the system described above are applied two coats of Applied Resistive Coating (ARC) PRI C-R-A / 2001 C-H-B (Layers 8 and 9).

In 2007, the first entry into the Unit 1 piping after the initial application, coating failures in the form of delaminations were observed. Failures occurred between the saturated carbon fiber and the Cabosil filled epoxy layer. At that time it was decided by KPFF to omit the final Cabosil filled epoxy layer (Layer 6). In 2008 the failures are most prominent between the ARC coats and the underlying Cabosil filled epoxy coat.

There are no dry film thicknesses reported for any of the layers. Original KPFF instructions were to apply the Cabosil filled epoxy at ¼" wet film thickness (WFT). However, the contractor had difficulty in hanging that thickness and so instructions were revised to apply it at 1/8" thick WFT.

During the initial applications, the recoat window for the PRI 2002-3-R-A / PRI 2000-5-HR-B was reported to be 3 weeks. During the 2008 application it was revised to 24 hours. However, overcoating was frequently performed within only a few hours.

The material safety data sheets report both epoxies as modified aliphatic polyamines.

The materials are shipped to the site in 200 gallon carboys and then dispensed by aliquots into a bucket which in turn is poured into a measuring bucket that has a piece of tape at the proper level for the specific quantity of material needed for one batch. The measured quantities of both components are poured into a clean bucket and mixed for a specific period of time.

The instruction sheets for the coating materials report the following volumetric mix ratios:

Primer, Saturating Resin, Epoxy Protective Coating (Layer 1): 4.06:1

Epoxy Bonding Agent (Layers 2 through 7) - Saturating Resin to Cabosil: 1:1.25

Applied Resistive Coating: 3.34:1

The instructions for mixing the Cabosil filled epoxy report that once mixed the coating should be separated into smaller volumes to increase the pot life. The instructions for mixing the ARC report that it is to be mixed for exactly 2 minutes. If mixed using a high shear mixing blade, it is to be performed at low speed. The mix times were strictly enforced by KPFF.

The instructions report the following recoat windows:

- Cabosil filled material over itself - 55 F: 24 hours, 72 F: 16 hours, 85 F: 2 hours.
- ARC over PRI Cabosil filled material – Same as Above
- ARC over itself - 55 F: 48 hours, 72 F: 36 hours, 85 F: 24 hours

The NSF certification reports that the recoat window is 4 hours at 72 F.

Temperature/humidity logs were kept by the contractor and are appended to the report. Temperatures in the pipe ranged from 55 F to 82 F with most readings in the 65 to 75 degree range. Humidity ranged from 15% to 44% with most of the readings between 20% and 30%.

Adhesion testing was performed by Corrpro in 2006 and 2008 using a hydraulic adhesion tester in accordance with ASTM D 4541, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers." A complete copy of the test data is attached to the report. The following is a summary:

- Testing performed in 2006 showed that adhesion failures generally occurred at less than 700 psi (64% of the tests) with the failure plane between the first ARC coat and the primer or between the primer and the fabric. In a few cases failure occurred between the layers of carbon fabric.
- A second set of tests was performed in 2008 on the failing 2006 coating. The dollies were applied to the ARC coating applied over the primed carbon fiber. Failures almost always occurred between the ARC coating and the primer applied directly to the fabric. Seventy-five percent of the failures (15 out of 20) occurred at less than 500 psi.
- A third set of testing was performed in 2008 along the fabric seams. Eighty-three percent of the tests (5 out of 6) failed at less than 556 psi. The plane of failure was between the first coat of the ARC and the primer applied over the seam.
- Testing performed in 2008 on material that was applied in 2008 resulted in significantly different results. Testing was performed at two different locations. Location 1 had two primer coats applied over the Cabosil coat and the underlying two layers of fabric. Location 2 had two coats of ARC over one coat of primer applied to the underlying fabric.

    a) Testing performed at Location 1 resulted in excellent coating adhesion with 83% (15 out of 18) of tests greater than 1000 psi. Failures occurred between the two prime coats.

b) At Location 2 one test resulted in a 1053 psi tensile adhesion and the second test resulted in a 557 psi value. In both cases failures occurred between the first ARC coat and the primer.

Copies of the referenced documents are included in Attachment A, Background Information.

RESULTS OF THE FIELD INVESTIGATION

The field investigation was performed on April 11, 2008 and consisted of visual assessments and adhesion tests, blister assessments and pH measurements.

Adhesion was assessed in accordance with ASTM D6677, "Standard Test Method for Measuring Adhesion by Knife". ASTM D6677 involves making an X-scribe in the paint film. The knifepoint is then inserted at the intersection of the two scribes and lifted. Adhesion is rated on the extent of coating removed on an even number scale of 0 to 10, with 10 being the best.

Blistering was evaluated in accordance with ASTM D714, "Standard Test Method for Evaluating Degree of Blistering of Paints". The standard evaluates blistering on the basis of frequency (few, medium, medium dense and dense) and size (even numbers 2 through 8 with 8 being the smallest). Visual standards are provided for comparison to field conditions.

The pH was measured by applying pH paper to a newly opened blister that contained fluid.

Detailed assessment data is provided in Table 1. The following is a summary of the field investigation results:

1. The ARC coating had delaminated from approximately 20% of the lined pipe surfaces.

2. Approximately 80% of the surfaces with ARC coating in place were blistered. The blisters ranged in size from ½" to 3/4' in diameter and were filled with water.

3. The blisters appear to have pinholes in them with brown viscous material seeping out.

4. The pH of the blister fluid was 11. The blister fluid had a paint odor.

5. Adhesion was poor between the ARC coats and the underlying Cabosil filled epoxy (ASTM D6677: 0).

6. Adhesion between the layers of Cabosil filled material varied :

    - Adhesion was generally poor on the seam (ASTM D6677: 0). When forcibly disbonded the failure occurred between a Cabosil filled epoxy coat and the underlying saturated fabric.

- Adhesion varied in the field of the fabric (ASTM D6677: 0-10). When the coating was forcibly disbonded in mid-sheet the underlying fabric did not appear saturated.

Photos documenting both conditions are included in Attachment B, Photo Summary.

SAMPLES

KTA-1: Cabosil filled layer with ARC topcoat delaminated from saturated fabric.

KTA-3: ARC topcoat(s) with brown staining.

KTA-4: Vial of blister fluid.

KTA-6: ARC topcoats.

KTA-7: Yellowed Cabosil filled material.

KTA-8: Large delamination from Cabosil filled material with Cabosil layer and ARC layer at seam.

KTA-9: ARC delaminations away from seam.

SUMMARY OF THE LABORATORY INVESTIGATION

A complete copy of the laboratory investigation is included in Attachment C, Laboratory Investigation. The following is a summary:

1. The white Cabosil filled coat ranged from approximately 18 mils 80 mils.
2. Two to three gray ARC coats were observed on each of the samples evaluated. The total dry film thickness of the ARC layer varied significantly.
   - Two samples (KTA-8 and KTA-9) ranged between 8.6 and 22.5 mils.
   - Three samples (KTA-1, KTA-3 and KTA-6) ranged between 18.2 and 53.4 mils.
3. Coating adhesion was subjectively assessed on sample KTA-1 (ARC applied to Cabosil layer) and was found to be poor. (The other samples did not contain the two layers so adhesion tests were not performed).

4. Microscopic examination of the ARC coat samples (KTA-1, KTA-3 and KTA-6, KTA-8 and KTA-9) showed craters in the top surface of the ARC-coat. The craters were similar in appearance to when solvent is released just prior to cure.

5. There was a brown sticky residue on all of the coating samples (both Cabosil filled coating and ARC coating).

6. The backs of the Cabosil filled samples had the impression of woven fabric.

7. Chemical analysis of blister liquid and the sticky brown deposits determined that the material was consistent with an amine.

8. Control samples of the ARC coating were mixed (1) in accordance with the manufacturers stated mix ratio, (2) using less catalyst then required (low amine concentrations) and (3) using more catalyst then required (high amine concentrations). Chemical analysis of the topcoat from samples KTA-1 and KTA-6 determined each to be an epoxy and consistent in formulation with the properly mixed control sample of the ARC. However, there was an abundance of amine found in the field samples when compared against the amine concentrations in the properly mixed laboratory sample.

9. Control samples of the Cabosil filled coating were mixed (1) in accordance with the manufacturers stated mix ratio, (2) using less catalyst then required (low amine concentrations) and (3) using more catalyst then required (high amine concentrations). Chemical analysis of the Cabosil layer from samples KTA-1, KTA-7 and KTA-8 determined each to be an epoxy and consistent in formulation with the properly mixed control sample of the Cabosil filled coating. However, there was an abundance of amine found in field sample KTA-7 when compared against the amine concentrations in the properly mixed laboratory sample. Only a small amount of amine was found in samples KTA-1 and KTA-8. Elevated moisture levels were found in these samples.

10. Samples of the Cabosil filled coatings and the ARC coatings, mixed at various ratios were allowed to age under various temperatures and humidity:

    - The Cabosil filled coating mixed at the specified ratio, amine blushed at 50-100% humidity, and 55-113F.

    - The ARC coating amine blushed at the correct mix ratio as well as the over -catalyzed version at ambient conditions and under humid cool conditions. The under- catalyzed ARC coating did not amine blush at ambient conditions.

11. One control sample of properly mixed Cabosil filled material that was analyzed directly after

cure was allowed to age in the laboratory and then reanalyzed. After one month, the amount of amine present of the surface increased when compared to the original chemical analysis. In addition, the amount of bound moisture present in the control sample also increased.

12. Test panels, abrasive blasted to achieve a profile of 2 to 3 mils, were primed with a Cabosil filled layer applied at $^1/_8''$ wet film thickness. Twenty-four hours later the panels were recoated with either another layer of the Cabosil filled coat or a layer of Applied Resistive Coating (ARC) topcoat. The panels were then allowed to cure at various temperatures and humidity. Tensile adhesion (pull-off strength) testing was performed on the cured test panels.

    - Adhesion testing of the Cabosil to Cabosil panels showed that adhesion decreased as a function of decreasing temperature at moderate humidity.

    - Adhesion testing of the ARC Coating to Cabosil remained consistent at all of the temperatures and humidities tested.

DISCUSSION

There is widespread blistering and subsequent coating delamination found on the lined cooling water piping in Unit 2 at the Intermountain Power Station in Delta, UT. The blistering and delaminations occurred primarily between the the ARC topcoats and the underlying Cabosil layer. The problem is widespread in that:

- The topcoat has already delaminated from approximately 20% of the coated pipe surfaces.
- Approximately 80% of all surfaces are blistered.
- All ARC-coated areas tested were poorly bonded.

To a lesser extent, delaminations and poor coating adhesion were observed between layers of Cabosil filled material. The failures and poor coating adhesion were located primarily along the fabric joints where additional Cabosil filled material was applied to the saturated fabric. In a few locations failures were found within the fields of the fabric. Forced removal of the coating exposed unsaturated fabric in these locations.

The blistering and poor coating adhesion between the layers of Cabosil filled material and between the ARC coating and the Cabosil filled material is a result of the formation of amines (amine blush) on the surface of the Cabosil material and throughout the cross section of the ARC coating. This is exemplified by the following field observations that were found throughout the lined pipe at Intermountain Power:

1. Amber colored blister fluid with a pH of 11.

2. Sticky brown sappy material deposited on the surface of the ARC coating.
3. Amber stained Cabosil filled material.

Typically, amine blush occurs when amine cured epoxies cure under cool, high humidity conditions. The amine portion of the coating separates as an oily film or droplets, often amber in color. The amine component reacts with moisture and atmospheric carbon dioxide to form ammonium bicarbonate and/or ammonium carbamate.

There are additional environmental conditions that can exacerbate the formation of amine blush. These include elevated carbon dioxide moisture levels. The amine compounds are often hygroscopic (absorb moisture) and are very efficient scavengers of carbon dioxide from the air. In confined spaces with human activity, such as in the pipe at the Intermountain Power Station, carbon dioxide concentrations can increase 2 to 3 times that normally found in the atmosphere. In the presence of gas burning heaters, the carbon dioxide concentrations could be even greater. These sources of heat may also produce abundant quantities of water vapor resulting is exacerbated blushing problems. It was reported that gas heaters were used to elevate the temperature in the pipe and so elevated carbon dioxide levels were likely. It is important to note that the humidity readings suggest that moisture levels were not elevated. Humidity between 20% and 30% were common in the pipe. Under these conditions amine blush is not expected.

As reported above, typically cool, high humidity conditions are required for the amine cured epoxies to blush. However, both of the coatings used at Intermountain power were found to blush even under moderate temperature and low humidity conditions (70 F and 50% humidity) in the KTA laboratory. Several laboratory tests were used to reach this conclusion:

1. Samples of the Cabosil filled coatings and the ARC coatings were mixed at the recommended ratios in the laboratory and were allowed to age under various temperatures and humidity. Both the Cabosil filled coating and the ARC coating blushed even at 50% humidity and 70 F (ambient conditions).

2. The Cabosil filled coating blushed even when it was mixed with deficient quantities of catalyst (amine).

3. The surface of a sample of Cabosil filled coating was analyzed directly after cure and then reanalyzed after one month. The amount of amine present on the surface increased when compared to the original chemical analysis.

4. Adhesion testing showed that there were significant reductions in adhesion between two layers of Cabosil filled material as temperature decreased under moderately humid conditions.

The adhesion testing performed by Corrpro also indicates that there are adhesion issues. Testing performed in 2006 clearly resulted in poor adhesion values. Using the hydraulic adhesion tester that was reported to have been used, adhesion tests greater than 1000 psi should have resulted. Furthermore the primary plane of failure (between the first ARC coat and the primer) is consistent with the results of the laboratory analysis. The primer resin is prone to blush even under ideal conditions resulting in a weak bond. The testing performed in 2008 on the 2006 applications is consistent with the above findings.

The testing performed on the 2008 applications was remarkably different. The testing resulted in 83% (15 out of 18) of tests greater than 1000 psi. Failures occurred between the two prime coats. While these test results are excellent there is still concern that retests performed at the next outage may result in different results. KTA bases this conclusion on the fact that the primer resin continues to form amine blush even after it has cured. Blushing could likely result in reduced coating adhesion over time.

Clearly amine blush should not form under laboratory conditions and in the even drier conditions down in the pipe unless there is a formulation problem with the coating. Laboratory testing showed that the samples of coating removed from the pipe were mixed consistent with the manufacturers recommended instructions.

The amine blush formation at Intermountain Power is not a result of mis-mixing where too much catalyst (amine component) is added to the coating. In fact, laboratory testing showed that the Cabosil filled coating blushed when the mix was deficient in amine (under catalyzed) and continued to blush long after the cure period. As a result of this finding and the relatively quick succession in which layers were applied it is doubtful that the blush was visible at the time of application.

This propensity to blush is also the likely cause of the tiny craters in the ARC coating. As discussed above the amines are water loving and will draw moisture in from the air. When the moist amine surfaces are overcoated, the moisture tries to escape, however, the coating cures before it is fully released - a crater results. This process also explains the reason that bound moisture was found in the coating.

It is important to note that there are a number of areas within the Unit 2 piping where the coating has delaminated from fabric that was not saturated. In these areas the ARC coating never bonded properly to the fabric and delaminations resulted. The area with unsaturated fabric is relatively small.

RECOMMENDATIONS

It is very likely that the remaining ARC coatings will continue to delaminate from the surface of the Cabosil filled material. Similarly the Cabosil filled material is likely to delaminate. While KTA has not inspected Unit 1 where there are many square feet of surface with Cabosil filled applications applied over saturated fabric, it is likely that delaminations will continue to occur as well. Furthermore since both coatings (ARC and Cabosil filled) have an inherent problem in the formulation that results in separation between layers, KTA cannot assure Intermountain Power that there will not be separation between the primer and the first fabric layer or between the two layers of saturated fabric.

Additional testing will be necessary in order to assess whether the coating will remain in place. This would include field adhesion testing and additional laboratory testing where sections of the pipe wall (cement and lining) would be examined.